Technical Paper
PLCopen Technical Committees 2 & 5
Logic, Motion, Safety

PLCopen Working Document, Version 0.41. Released as is.

Date: April 17, 2008

Total number of pages: 15

The following paper

Logic, Motion, Safety

is an official PLCopen document.

It summarises the results of the Technical Committees 2 – Functions and 5 – Safety during several meetings, and containing contributions of all its members.

Name	**Company**
Klas Hellmann	Phoenix Contact
Jochen Ost	Bosch Rexroth
Candido Ferrio	Omron Yaskawa Motion Control
Josep Lario	Omron Yaskawa Motion Control
Armin Wenigenrath	Schneider Electric
Willi Gagsteiger	Siemens
Bernard Mislewicz	Siemens
Roland Schaumburg	Danfoss
Frank Bauder	Omron Europe
Jürgen Hipp	ISG
Wolfgang Fien	Berger Lahr
Harald Buchgeher	KEBA
Stefan Pollmeier	ESR
Christian Fügner	Baumüller
Eelco van der Wal	PLCopen

Change Status List:

Version number	**Date**	**Change comment**
V 0.1	June 06, 2007	First release after kick-off meeting on March 15, and pré work done by Klas Hellmann and Eelco van der Wal in June 2007.
V 0.2	June 12, 2007	As result of the meeting in Neuremberg.
V 0.3	July 11, 2007	As result of the meeting in Niederschopfheim
V 0.4	Sept. 28, 2007	As result of the meeting in Neuremberg
V. 041	April 17, 2008	First released version with minor correctional changes. Incomplete SFC example removed

Contents

1 Combining Logic, Motion and Safety – an integral approach

1.1. Goal

The organization PLCopen published several technical documents in areas like motion control and safety, besides the IEC 61131-3 standard focussed to the logic.
With the merge of these different technologies, logic, motion and safety, on one environment, a need for examples of these combinations arose.
This document provides some of these examples. As such it adds to other PLCopen documents, like Motion Control Part 3 – User Guidelines, as created within TC2 – Functions, or Safety Part 2 – User Guidelines, as created within TC5 – Safety. In addition, results from other organizations are used, like OMAC.

The combination of logic, motion and safety best can be done via a structured approach. This document provides guidance for such an approach, although other approaches are of course possible. All provided solutions are supplied as example only to show the principal operation. and not tested. Also, they can be solved in different ways, and the way presented does not have to be the best one for your particular applications.

1.2. Definitions

Logic as used here is in the context of the IEC 61131-3 standard on programming languages.
Motion control is the movement of a single axis / motor, as well as synchronized action of several (servo) motors, as specified by PLCopen Technical Committee 2 – Functions.
Safety in this document is the machine safety focused to allowing operating personell to work safely, especially as defined in the PLCopen TC5 Safety specifications Part 1 and Part 2.

1.3. References

IEC 61131-3 – Part 3 of the IEC (International Electrotechnical Commission) 61131 standard, focused to the programming languages for programmable logical controllers. Check www.iec.org for more information.
PLCopen Motion Control – the suite of PLCopen specifications dedicated to motion control as published on the PLCopen website. Currently consisting of 5 parts, including Part 3 – User Guidelines. Check www.plcopen.org for more information under TC2.
PLCopen Safety - the suite of PLCopen specifications dedicated to safety as published on the PLCopen website. Currently consisting of 2 parts, including Part 2 – User Guidelines. Check www.plcopen.org for more information under TC5.

1.4. Outline

This document contains two examples showing how to combine the PLCopen motion and safety specifications in applications. If more examples become available, an update can be done.

2 Introduction

Within the application program one can identify 2 parts:

1. Functional application – the program section that deals with the non-safety section. It contains the logic and motion functionalities.
2. Safety application – the program section that deals with the safety application

Both parts exchange data to contol the overall process. The safety part basically enables safety relevant action. The functional application however needs to control the process within the monitored limits. (e.g. to stop drives in case of an ermergency stop).

2.1. Motion and safety state diagrams

There are state diagrams defined in both the Motion Control specifications, as part of the functional application, and the Safety specification. These state diagrams reflect the state of the device. These two state diagrams are separate implemenations, have little effect on each other, and are normally used in parallel. The safety application can effect the functional application, and so the motion control state diagram per axis or per group, especially if a safety conditionis valid.

2.2. Safety reactions and conditions

The safety application supports two tasks:

- ***Safety reaction*** – resulting in a safe state as quick as possible after certain monitored conditions are not met (e.g. activating the emergency stop button or blocking a light curtain)).
- ***Safety condition*** – this have to ensure a safe state before the action can be done (e.g. unlocking a guard to enter the hazardous area. The precondition is that the area is safe (no movement)). The functional application has to take care that it fulfills these requirements (like safely limited speed).

Note: in case of a fail safe function, either of the safety application itself or a safe actor, the drive will perform a fail safe reaction and will not perform any motion related actions anymore. This fail safe reaction will be reflected (in the end) in the axis state diagram as an error.

3 Machine example 1

Description of the safety requirements
This example describes a machine with two electric drive systems within a working area where an operator needs access to e.g. for process diagnosis, set-up activities or to clear a material jam.
The access to the working area is provided by an interlocking guard with guard locking. The locking is required due to the fact that the operator could get access to the hazardous area before a stop of the drive system is be performed completely.
In emergency situation the drive systems needs to be stopped in accordance with stop category 1 (EN60204).
A mode selector is used to switch the machine between automatic and set-up mode.
Within the set-up mode the guard door can be opened and the drive systems enabled to move with a safely limited speed by using an enabling device.

The emergency stop (via SF_EmergencyStop) acts superimposed to all other safety functions and puts the drive systems into a safe standstill (via SF_SafeStop1) in accordance with stop category 1 of EN60204-1.

After an emergency stop, the restart of the machine is only possible after the emergency button is released and a reset signal is given (via SF_EmergencyStop)

The (normal) operation of the machine is only possible within the automatic mode (via SF_ModeSelector) and the guard door closed (via SF_GuardMonitoring) and locked (via SF_GuardLocking).

The guard door lock can be released within the set-up mode (via SF_ModeSelector) or after an emergency stop (via SF_EmergencyStop) as soon as the drive systems are performing a safe standstill (via SF_SafelyLimitedSpeed or SF_SafeStop1)

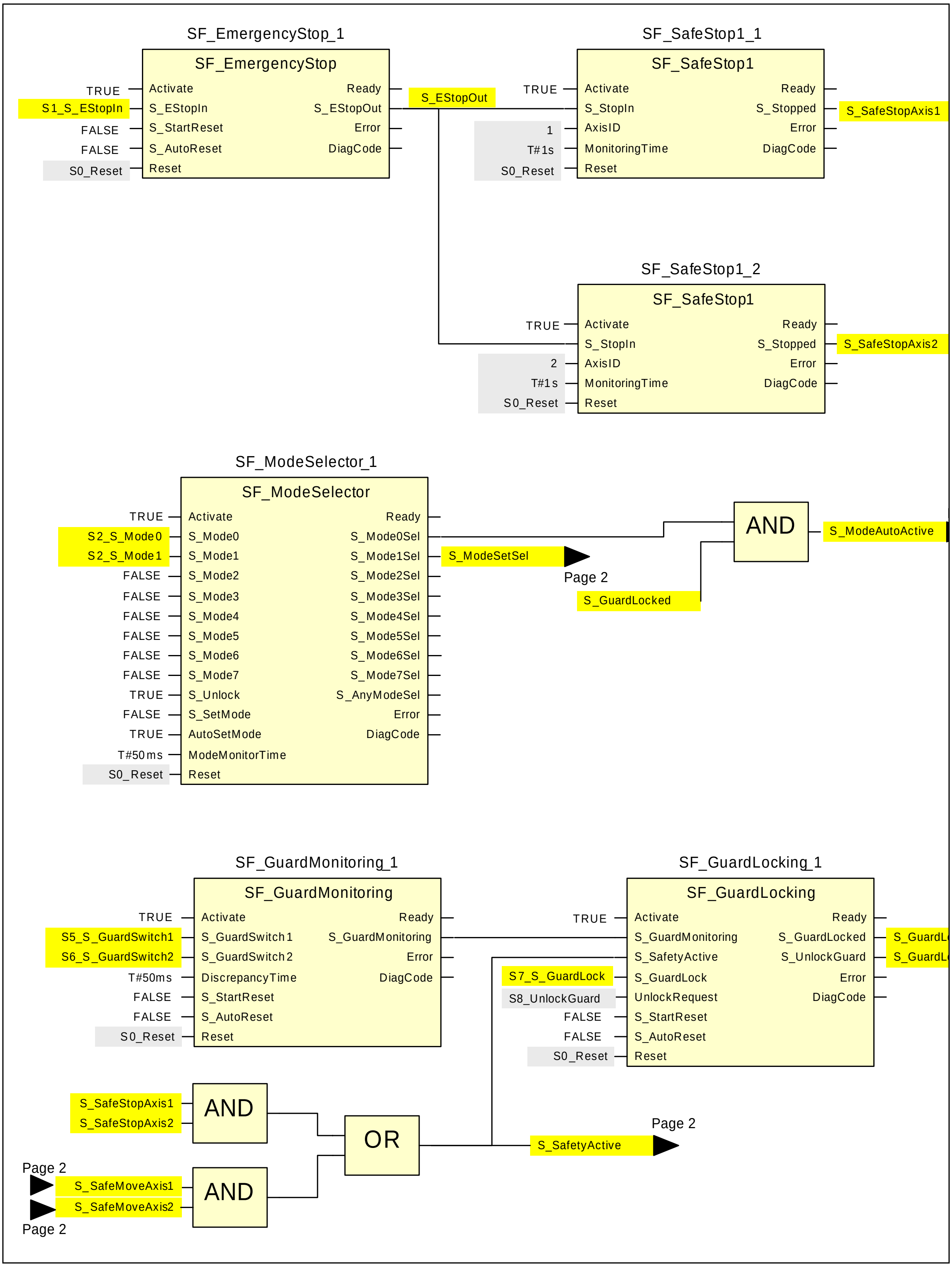
In the set-up mode (via SF_ModeSelector) the drive systems can be switched with the enabling device (via SF_EnableSwitch) into a mode where movement with safely limited speed is allowed (via SF_SafelyLimitedSpeed). The drive system can be moved by the motion controller via the standard command values. The drive itself has to guarantee safely that the speed limit gets not exceeded. (Note: If the motion control command values are greater than the parameterized limit the drive system performs a fail-safe reaction independently.)

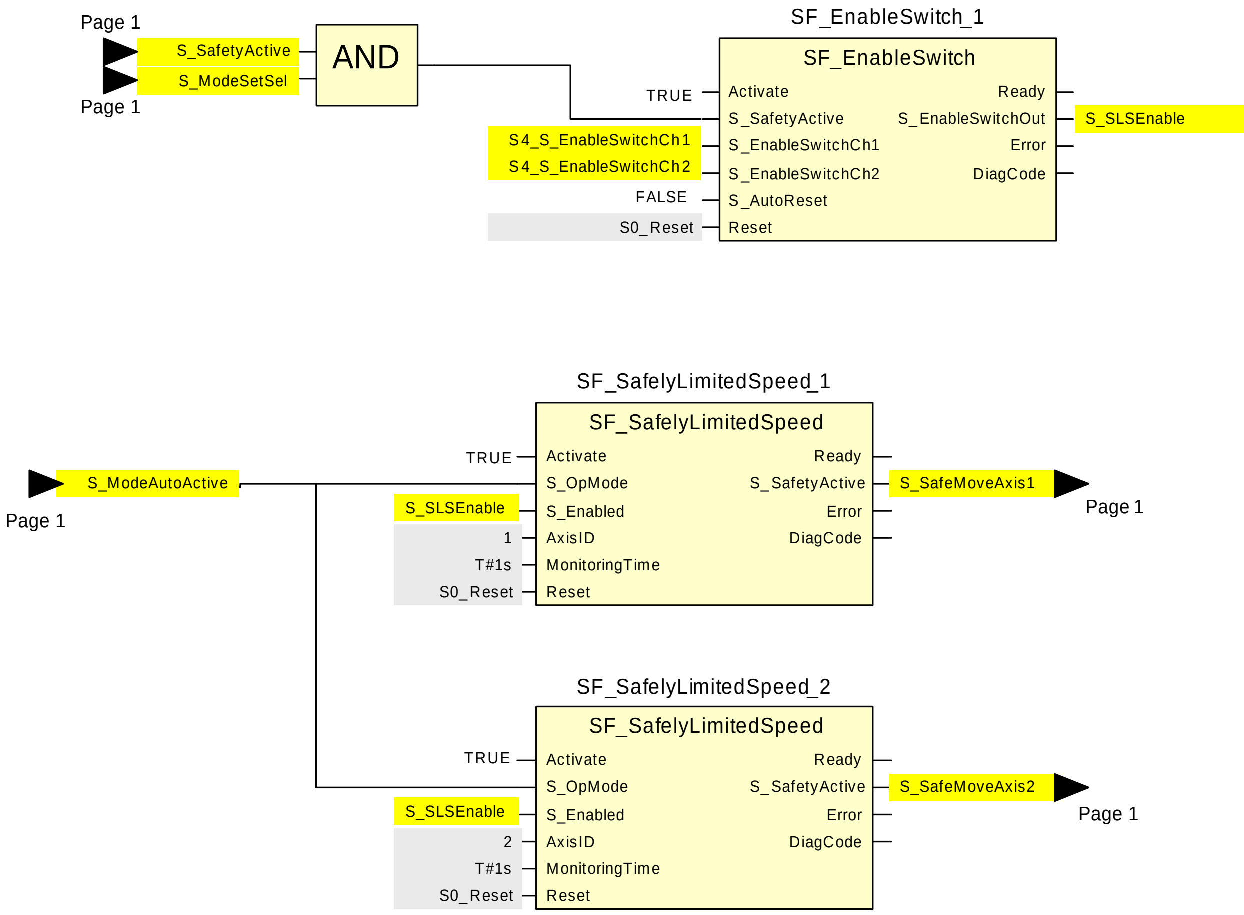
Without an enable signal (SF_EnableSwitch) the drive system stays in a safe standstill mode, where the speed gets monitored to be zero (SF_SafelyLimitedSpeed) as long set-up mode is selected. (Note: In this case the SF_SafelyLimitedSpeed FB puts the drive into a safe operational stop in accordance with stop category 2 (EN60204) and acts like the SF_SafeStop2 FB)

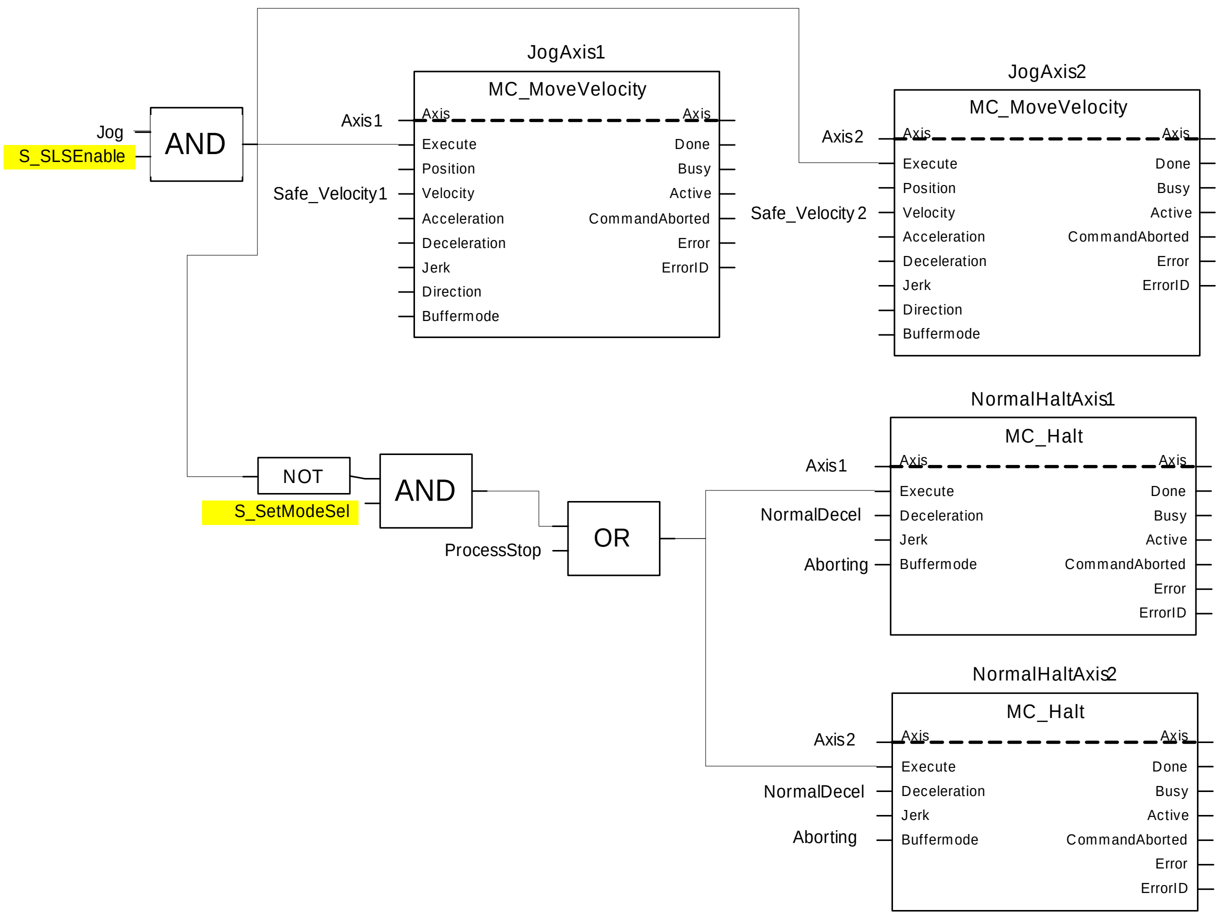
There are only two operation modes regarding safety. In Automatic mode no safety functions have to be active. If this mode is not selected, safety has to be ensured. The drive FBs differentiate only between a safe and a non-safe (operation) mode.

If a non-automatic mode is selected and the enable switch is not activated the SF_SafelyLimitedSpeed acts as a SF_SafeStop2.

To open the guard after a stop under normal operation conditions a non-automatic mode has to be selected by the mode selector switch first. Also the user has to request the release the interlock by setting the S8_UnlockGuard signal.



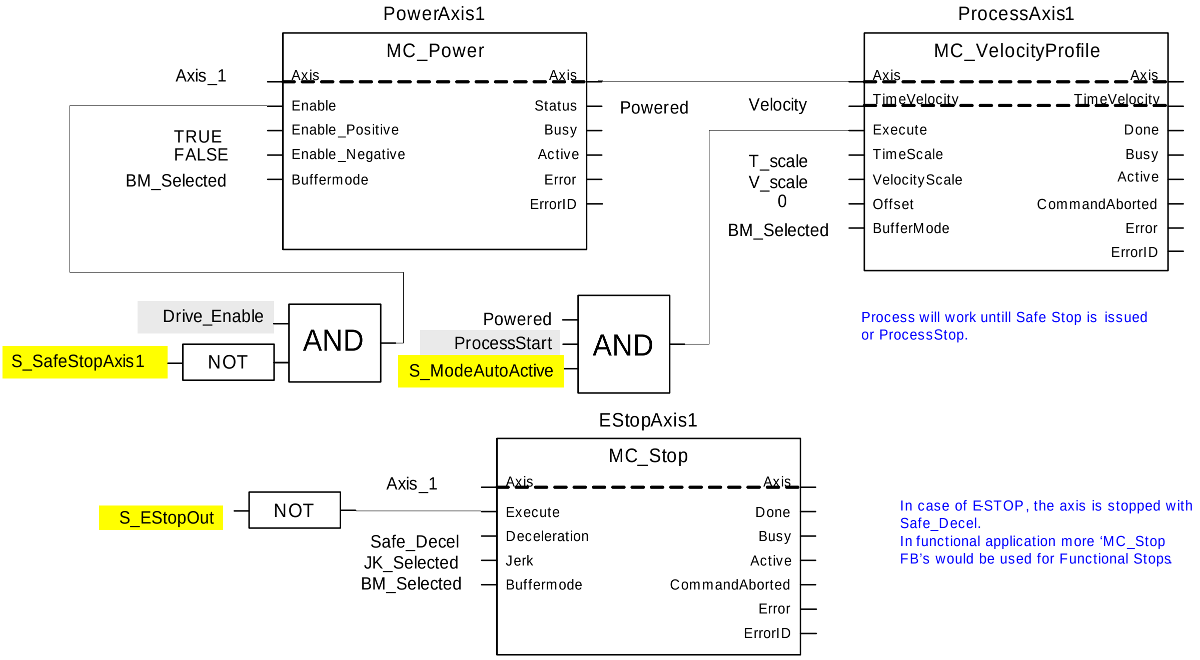

Page 1
S_SafetyActive
S_ModeSetSel
Page 1
AND
SF_EnableSwitch_1
SF_EnableSwitch
TRUE
Activate
Ready
S_SafetyActive
S_EnableSwitchOut
S_SLSEnable
S4_S_EnableSwitchCh1
S4_S_EnableSwitchCh2
S_EnableSwitchCh1
Error
S_EnableSwitchCh2
DiagCode
FALSE
S_AutoReset
S0_Reset
Reset
SF_SafelyLimitedSpeed_1
SF_SafelyLimitedSpeed
TRUE
Activate
Ready
S_ModeAutoActive
Page 1
S_OpMode
S_SafetyActive
S_SafeMoveAxis1
Page 1
S_SLSEnable
S_Enabled
Error
1
AxisID
DiagCode
T#1s
MonitoringTime
S0_Reset
Reset
SF_SafelyLimitedSpeed_2
SF_SafelyLimitedSpeed
TRUE
Activate
Ready
S_OpMode
S_SafetyActive
S_SafeMoveAxis2
Page 1
S_SLSEnable
S_Enabled
Error
2
AxisID
DiagCode
T#1s
MonitoringTime
S0_Reset
Reset

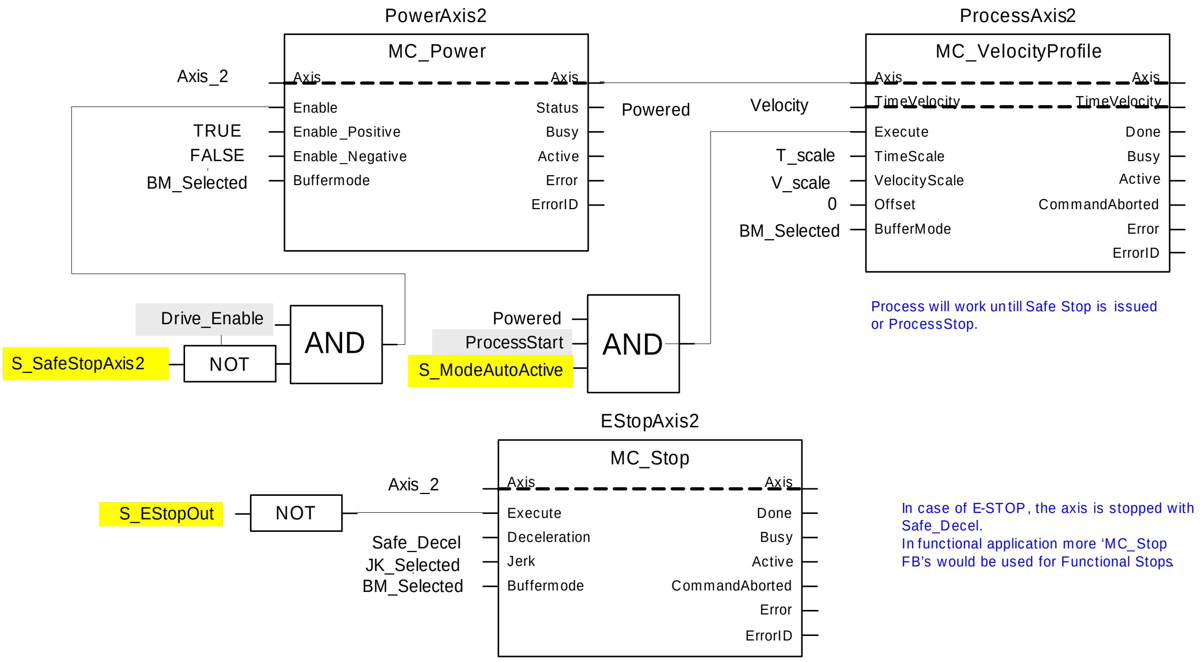


MC_Halt is used here because the halting mode can be aborted by another command, which in case of MC_Stop not the case is.
Condition S_SLSEnable: Mode is SetUp, drives are in safe condition, the Enable switch is pressed.

If Jog SET and S_SLSEnable TRUE, the MoveVelocity is executed.
If Jog NOT SET or S_SLSEnable FALSE, the axis is stopped via MC_Stop.
These MC_Stop FBs are only applicable if the mode is set to SetUp.

<Note: the usage of safe variables in the functional application (identified by S_ and marked yellow) is implementation dependent: it can be that the development system does not support the safe variable in the functional application and (implicitly) converts these to BOOL.>


PowerAxis1
MC_Power
Axis_1
Axis
Axis
Enable
Status
Enable_Positive
Busy
Enable_Negative
Active
Buffermode
Error
ErrorID
TRUE
FALSE
BM_Selected
Powered
Drive_Enable
AND
S_SafeStopAxis1
NOT
Powered
ProcessStart
S_ModeAutoActive
AND
ProcessAxis1
MC_VelocityProfile
Axis
Axis
TimeVelocity
TimeVelocity
Execute
Done
TimeScale
Busy
VelocityScale
Active
Offset
CommandAborted
BufferMode
Error
ErrorID
Velocity
T_scale
V_scale
0
BM_Selected
Process will work untill Safe Stop is issued
or ProcessStop.
EStopAxis1
MC_Stop
Axis_1
Axis
Axis
S_EStopOut
NOT
Execute
Done
Deceleration
Busy
Jerk
Active
Buffermode
CommandAborted
Error
ErrorID
Safe_Decel
JK_Selected
BM_Selected
In case of ESTOP, the axis is stopped with
Safe_Decel.
In functional application more 'MC_Stop
FB's would be used for Functional Stops


PowerAxis2
MC_Power
Axis_2
Axis
Axis
Enable
Status
Enable_Positive
Busy
Enable_Negative
Active
Buffermode
Error
ErrorID
TRUE
FALSE
BM_Selected
Powered
Drive_Enable
AND
S_SafeStopAxis2
NOT
Powered
ProcessStart
S_ModeAutoActive
AND
ProcessAxis2
MC_VelocityProfile
Axis
Axis
TimeVelocity
TimeVelocity
Execute
Done
TimeScale
Busy
VelocityScale
Active
Offset
CommandAborted
BufferMode
Error
ErrorID
Velocity
T_scale
V_scale
0
BM_Selected
Process will work untill Safe Stop is issued
or ProcessStop.
EStopAxis2
MC_Stop
Axis_2
Axis
Axis
S_EStopOut
NOT
Execute
Done
Deceleration
Busy
Jerk
Active
Buffermode
CommandAborted
Error
ErrorID
Safe_Decel
JK_Selected
BM_Selected
In case of E-STOP, the axis is stopped with
Safe_Decel.
In functional application more 'MC_Stop
FB's would be used for Functional Stops

4 Machine example 2

4.1. Introduction

This application also uses 2 axes, in this case related as master and slave via the gear functionality. The safe part of the example is the same as in example 1 as the requirements for safety are the same, e.g. a safety limited speed (SLS) functionality, which is activated via an enable switch, so material could be taken out of the machine in practice, and mode selector, emergency stop, and guard monitoring and locking.

In order to fulfill the requirements in synchronized motion (GearIn in this case) the modifictions in this example are only applied in the motion portion.
As the synchronization of the axes involved is required for every moment of the machine operation all motion operations are only applied to the master axis as long as the synchronization is active. This allows applying all safety functions to the machine without causing any damage to it by loosing the synchonisation.
In order to make sure that the right maximum value for the safe limied speed ist used for the master axis the applied logic gives the right value by using he minimum value from axis 1 and axis 2 considering the used gear ratio.

The following safety principles are used in the application:

1.- Each of the axis in the machine has a certain absolute velocity (no kinematics involved) wich makes that axis dangerous and should trigger safety fault in case it is exceeded.

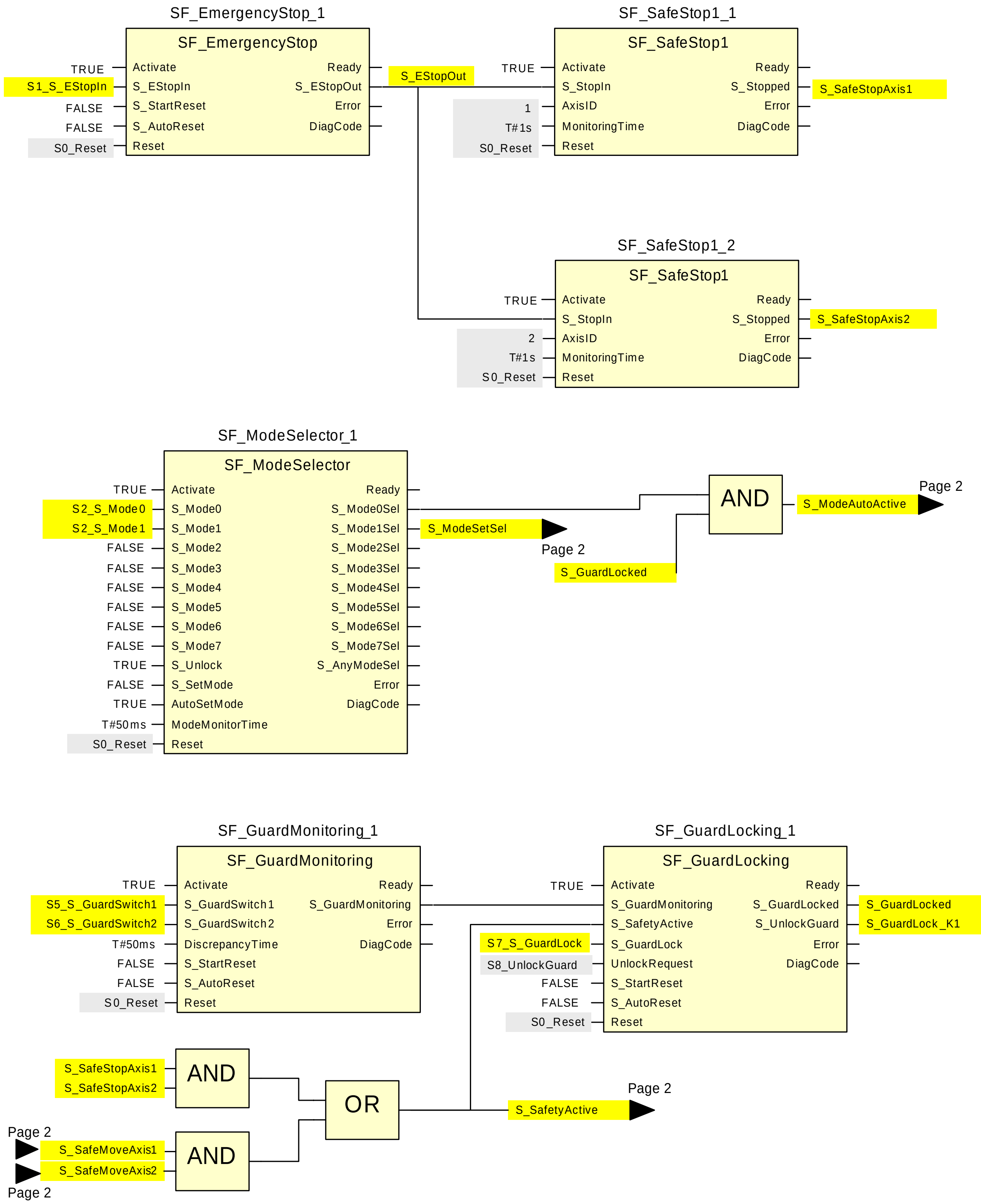
2.- The speed relationships between the axes must be respected in order to continue the process of the machine (this means that the slave axis cannot run at an arbitrary speed nor change the gear ratio of without damaging the “production”).

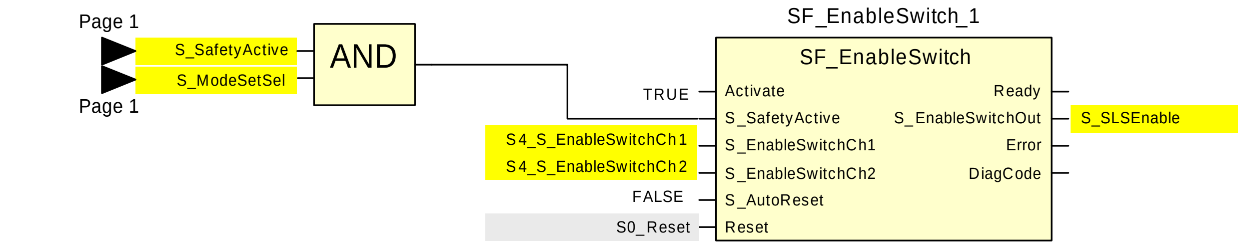
3.- By lowering the master speed, all the synchronized axis to it proportionally lower their speeds. This is a countermeasure to avoid the safety fault to be triggered, so should be applied while the safety condition is applicable. The difference is that in this case both the master speed itself plus the resulting speed on the slave through the ratio should be taken into account to choose the right master reference.

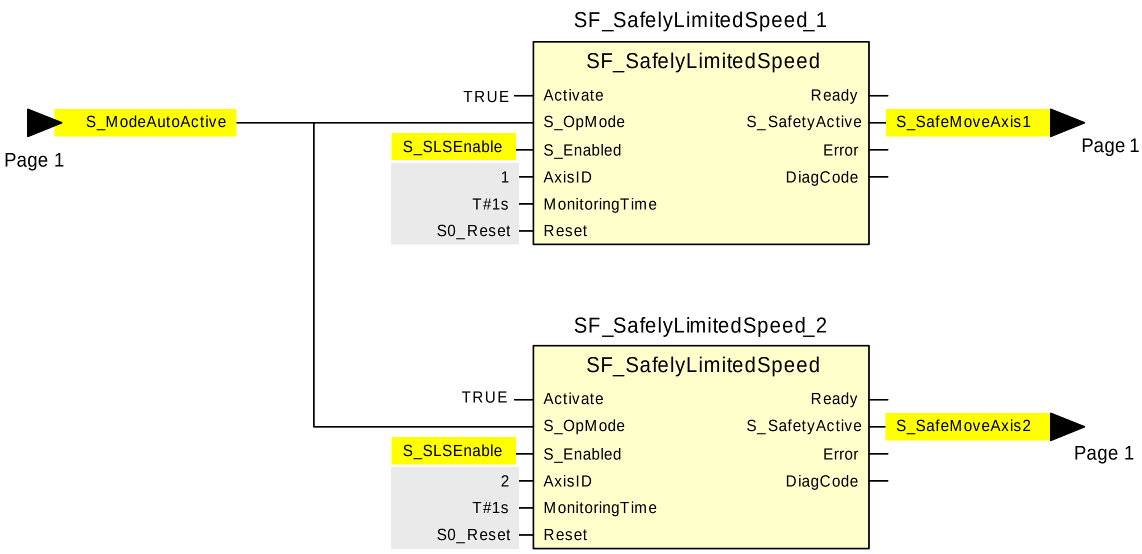
4.- If the application requires variable ratios for slaves, always the worst case should be taken into account in order to decide the amount of speed reduction in master (e.g. the highest ratio, or the CAM points where slave speed is maximum). Although the application could establish this maximum value during run time, and as such always optimizing the master reference to achieve the maximum machine operation speed within the safety limits set, but this is not compulsory and many times not a priority.

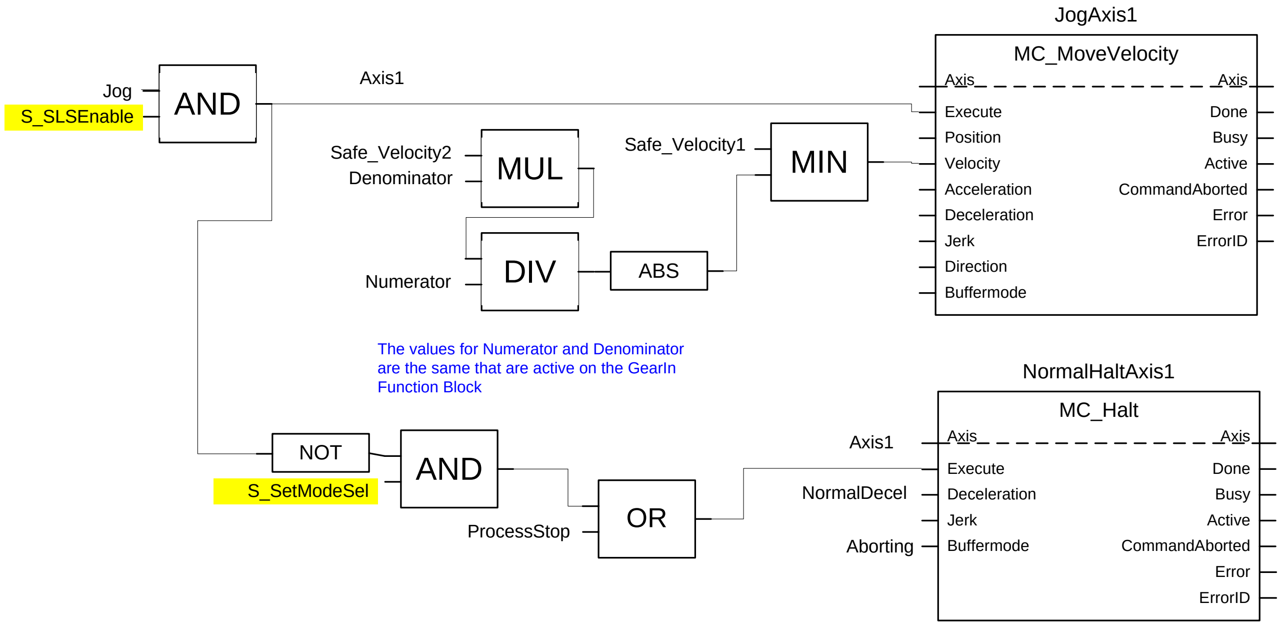
5.- And most important : the safety condition we want to check does not change regardless the type of master-slave schema applied in the machine, because the safety functionality checks the velocity conditions wich are dangerous in the machine. Safety does not care about synchronized axis or not.

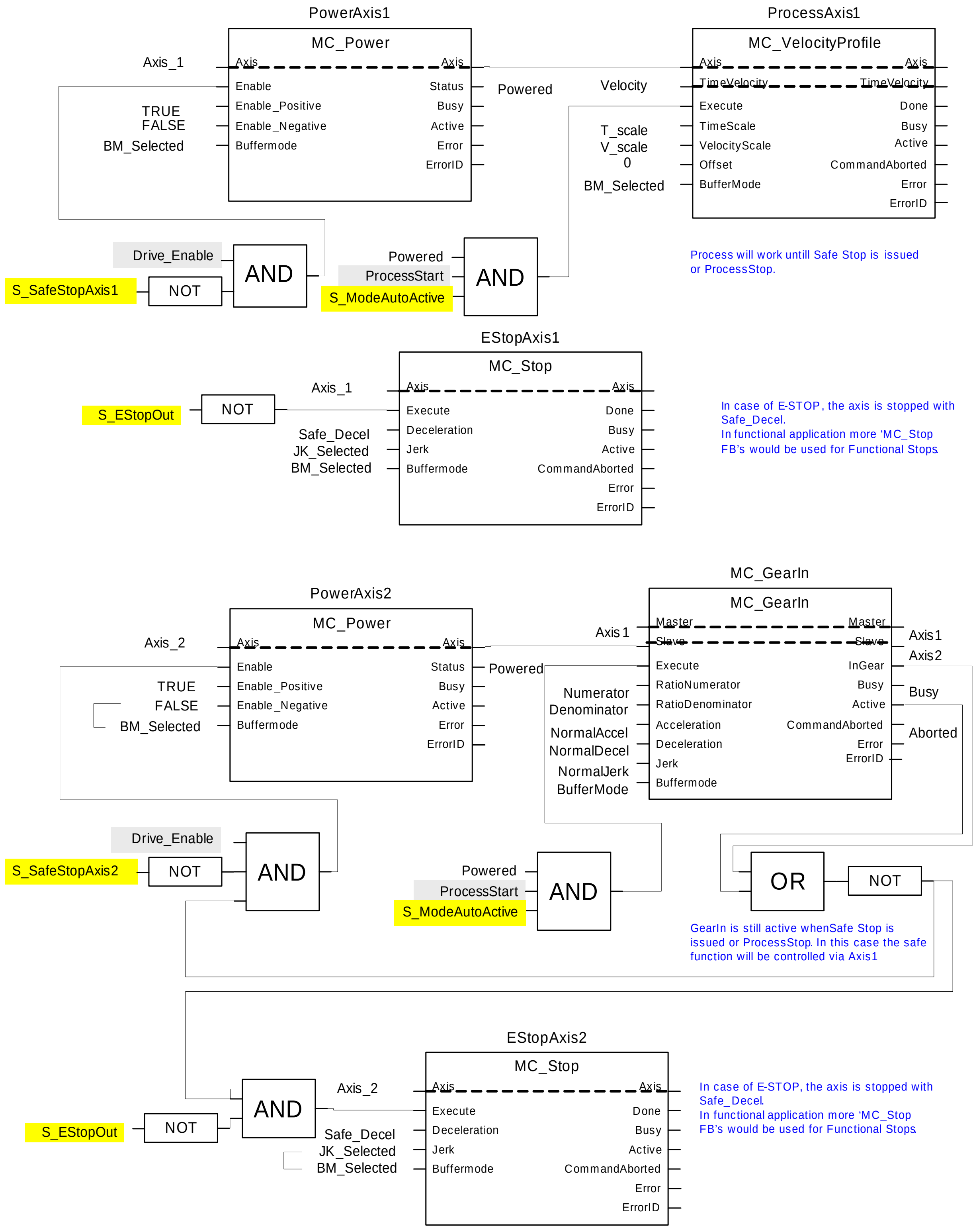
4.2. Program Example




Page 1
S_SafetyActive
S_ModeSetSel
Page 1
AND
SF_EnableSwitch_1
SF_EnableSwitch
TRUE
Activate
S_SafetyActive
S4_S_EnableSwitchCh1
S4_S_EnableSwitchCh2
S_EnableSwitchCh1
S_EnableSwitchCh2
FALSE
S_AutoReset
S0_Reset
Reset
Ready
S_EnableSwitchOut
Error
DiagCode
S_SLSEnable

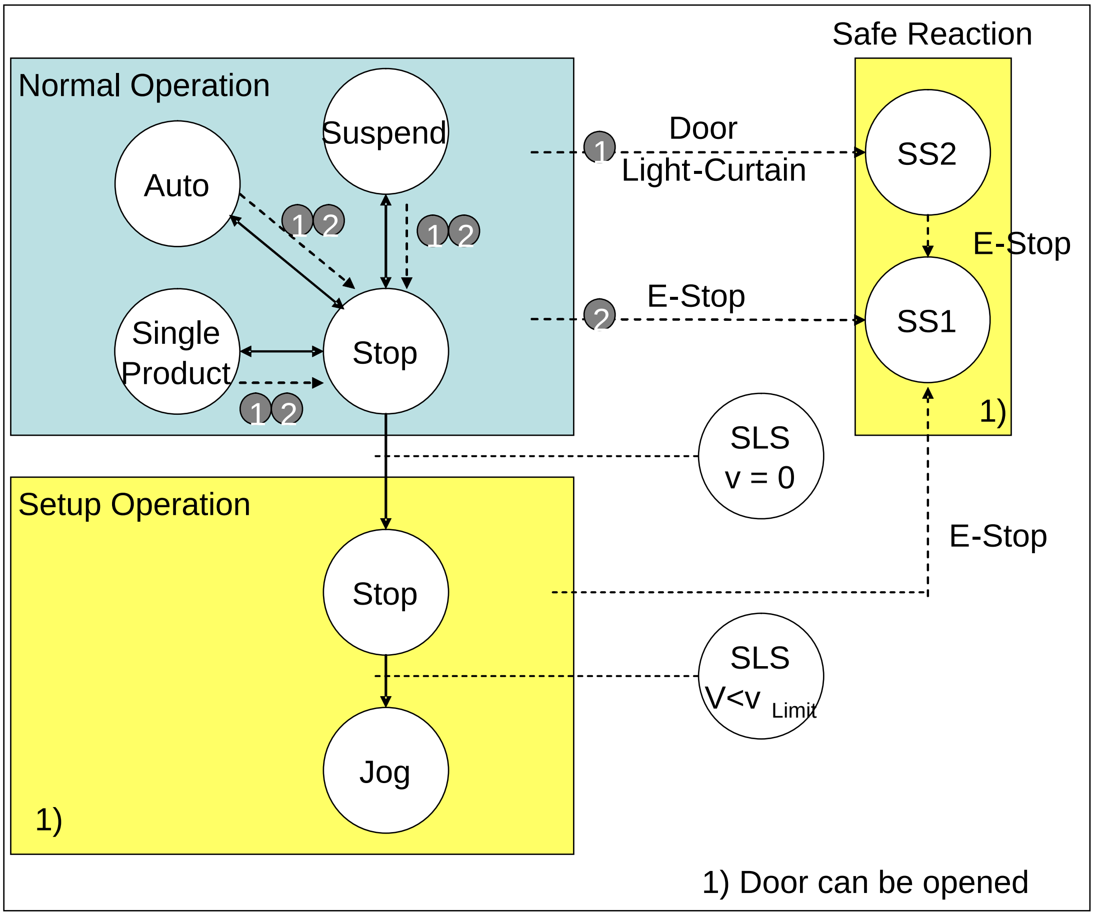

SF_SafelyLimitedSpeed_1
SF_SafelyLimitedSpeed
TRUE
Activate
S_ModeAutoActive
Page 1
S_OpMode
S_SLSEnable
S_Enabled
1
AxisID
T#1s
MonitoringTime
S0_Reset
Reset
Ready
S_SafetyActive
Error
DiagCode
S_SafeMoveAxis1
Page 1
SF_SafelyLimitedSpeed_2
SF_SafelyLimitedSpeed
TRUE
Activate
S_OpMode
S_SLSEnable
S_Enabled
2
AxisID
T#1s
MonitoringTime
S0_Reset
Reset
Ready
S_SafetyActive
Error
DiagCode
S_SafeMoveAxis2
Page 1


JogAxis1
MC_MoveVelocity
Jog
S_SLSEnable
AND
Axis1
Axis
Axis
Execute
Position
Velocity
Acceleration
Deceleration
Jerk
Direction
Buffermode
Done
Busy
Active
CommandAborted
Error
ErrorID
Safe_Velocity2
Denominator
MUL
Safe_Velocity1
MIN
Numerator
DIV
ABS
The values for Numerator and Denominator are the same that are active on the GearIn Function Block
NormalHaltAxis1
MC_Halt
NOT
S_SetModeSel
AND
ProcessStop
OR
Axis1
NormalDecel
Aborting
Axis
Axis
Execute
Deceleration
Jerk
Buffermode
Done
Busy
Active
CommandAborted
Error
ErrorID


PowerAxis1
MC_Power
Axis_1
Axis
Axis
Enable
Status
Powered
TRUE
FALSE
BM_Selected
Enable_Positive
Enable_Negative
Buffermode
Busy
Active
Error
ErrorID
ProcessAxis1
MC_VelocityProfile
Axis
Axis
Velocity
TimeVelocity
TimeVelocity
Execute
Done
T_scale
V_scale
0
BM_Selected
TimeScale
VelocityScale
Offset
BufferMode
Busy
Active
CommandAborted
Error
ErrorID
Drive_Enable
S_SafeStopAxis1
NOT
AND
Powered
ProcessStart
S_ModeAutoActive
AND
Process will work untill Safe Stop is issued
or ProcessStop.
EStopAxis1
MC_Stop
Axis_1
Axis
Axis
S_EStopOut
NOT
Execute
Done
Safe_Decel
JK_Selected
BM_Selected
Deceleration
Jerk
Buffermode
Busy
Active
CommandAborted
Error
ErrorID
In case of E-STOP, the axis is stopped with
Safe_Decel.
In functional application more 'MC_Stop
FB's would be used for Functional Stops
PowerAxis2
MC_Power
Axis_2
Axis
Axis
Enable
Status
Powered
TRUE
FALSE
BM_Selected
Enable_Positive
Enable_Negative
Buffermode
Busy
Active
Error
ErrorID
MC_GearIn
MC_GearIn
Axis 1
Master
Master
Axis1
Slave
Slave
Axis2
Execute
InGear
Numerator
Denominator
RatioNumerator
RatioDenominator
Busy
Active
Busy
NormalAccel
NormalDecel
NormalJerk
BufferMode
Acceleration
Deceleration
Jerk
Buffermode
CommandAborted
Error
ErrorID
Aborted
Drive_Enable
S_SafeStopAxis2
NOT
AND
Powered
ProcessStart
S_ModeAutoActive
AND
OR
NOT
GearIn is still active whenSafe Stop is
issued or ProcessStop. In this case the safe
function will be controlled via Axis1
EStopAxis2
MC_Stop
AND
Axis_2
Axis
Axis
S_EStopOut
NOT
Execute
Done
Safe_Decel
JK_Selected
BM_Selected
Deceleration
Jerk
Buffermode
Busy
Active
CommandAborted
Error
ErrorID
In case of E-STOP, the axis is stopped with
Safe_Decel.
In functional application more 'MC_Stop
FB's would be used for Functional Stops

4.3. State Diagram explanation

The conditions and states can be shown in a (generic) state diagram.
From all the modes the emergency stop can be issued, transiting to the safe stop 1 (SS1) mode. In normal operation this is reflected by the Stop functionality.
In normal operation, a light curtain or door switch can protect the hazardous area, and if activated result in the safe reaction safe stop category 2 (SS2), also reflected by the Stop functionality in normal operation.



For the emergency stop functionality, we want one switch for the whole machine. We need to connect the status of this knob (On or Off) to the application. Also, we need to restart the machine after releasing and acknowledging the emergency button.